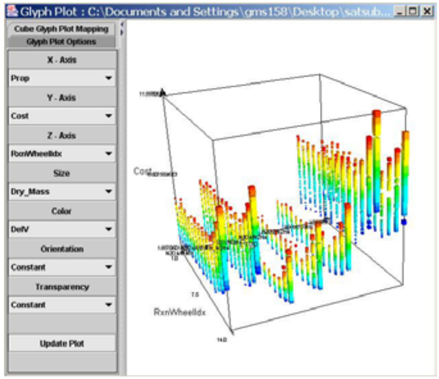
The ARL Trade Space Visualizer (ATSV) : An Engineering Decision-Making Tool

Gary Stump
Mike Yukish
Jay Martin

Product and Process Design Department
ARL/Penn State

Timothy W. Simpson

Industrial and Mechanical Engineering Department
Penn State



Outline

- Underlying philosophy & vision
- Introduce the ARL Trade Space Visualizer (ATSV)
- Recent efforts that have extended the ATSV capabilities
  - Derivative display
  - Feature finder process
  - Uncertainty visualization
- Summary

Vision

Develop advanced design environments...

computer tools, applications, and networks to support modeling, simulation, analyses, workflow, collaboration, data vaulting, information access

that will allow design teams to…

- eliminate avoidable design errors...

  modeling, simulation, and analysis; access to domain experts (collab); access to legacy and current design knowledge

- with no waiting...

  workflow, collaboration, faster codes, central data repository

- and remember everything

  configuration management, data vaulting, rationale capture; all models, documents, analyses results, etc. related to the design

Underlying Philosophy

- The assumption that we can capture a decision maker's preference *a priori* is **wrong**.
    - People want to shop, gain intuition about trades

Underlying Philosophy

- The assumption that we can capture a decision maker's preference *a priori* is **wrong**.
    - People want to shop, gain intuition about trades
- Design is decision making, optimization is automated decision making
    - "Automation can make people stupid" – Gary Klein

Underlying Philosophy

- The assumption that we can capture a decision maker's preference *a priori* is **wrong**.
    - People want to shop, gain intuition about trades
- Design is decision making, optimization is automated decision making
    - "Automation can make people stupid" – Gary Klein
- Trade space exploration is a complex task, requires a powerful interface
    - "No kazoo concerts in Carnegie Hall" – Bran Ferran
    - Violin, F-16, ATSV are complex and noninutuitive initially…but empower the user with training and experience

Design by Shopping

- Large number of feasible designs can be generated using design automation.
- By exercising design automation, the feasible design space can be graphically displayed, allowing a decision-maker to form a preference *after* viewing the design space.
- Support search of complex design spaces using multidimensional visualization techniques.

Trade Space Exploration Using the ATSV

Build Model

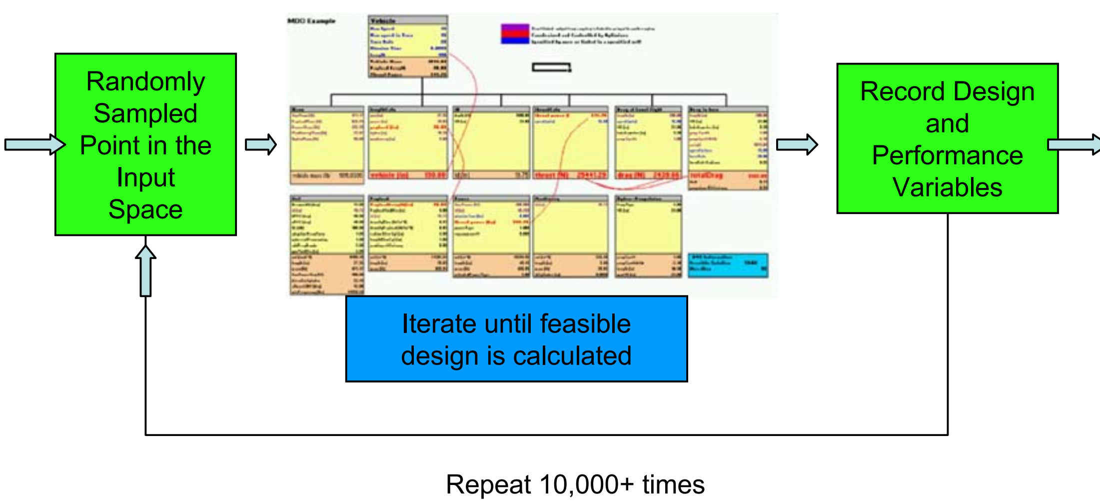
- Assemble to generate 10,000+ pts
- Models are based on design rules found in open literature

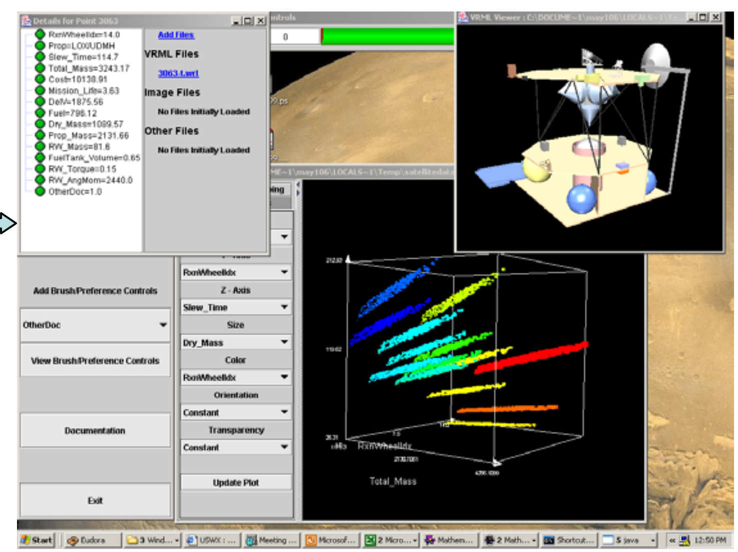
Run Experiments

- Focus on trade study of interest
- 3000-4000 designs
- Augment design with geometry and more

Explore

- ATSV
- Look for known trends
- Apply constraints
- Visualize preference structures and Pareto frontiers
- Optimize





Rule capture for subsystems

- Use Mathematica
- Gather design rules in a format that is both readable and executable
- Supports literate programming paradigm
- Mathematical typesetting greatly enhances readability

(* compute the idealized theoretical impulse *)

$$\text{heoreticalImpulse} = \sqrt{\frac{2\,k\,r\,tc}{gc\,(k-1)}\left(1-\left(\frac{1}{pRatio}\right)^{\frac{k-1}{k}}\right)} + \frac{1}{pRatio}\,areaRatio\,\sqrt{\frac{r\,tc}{k\,gc\,\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}}};$$

$$\text{xhaustVelocity} = \sqrt{\frac{2\,k\,gc\,r\,tc}{k-1}\left(1-\left(\frac{1}{pRatio}\right)^{\frac{k-1}{k}}\right)};$$

(* λ is the correction factor due to the exhaust not exiting parallel to the engine *)

$$\lambda = \frac{1+\mathrm{Cos}[coneAngle\,°]}{2.};$$

(* cf, the thrust coefficient, is calculated from first principles,
with the .002 factor tossed in to make the results correspond with WinPro *)

$$\text{f} = (\lambda - .002)\sqrt{\frac{2\,k^2}{k-1}\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}\left(1-\left(\frac{1}{pRatio}\right)^{\frac{k-1}{k}}\right)} + \frac{1}{pRatio}\,areaRatio;$$

Array Design Rules

```
arraySize[frequency_, beamwidth_, dbAtWidth_, depth_] :=
 Module[{speedOfSound, wavelength, sigStrength, sizeOfArray, solArray},

  speedOfSound = 1492.9 + depth/61;

  wavelength = speedOfSound/(1000 frequency);

  sigStrength = (2 BesselJ[1, (π sizeOfArray Sin[beamwidth °])/wavelength]) /
                ((π sizeOfArray Sin[beamwidth °])/wavelength);

  eq = 10 Log[10, sigStrength^2] == dbAtWidth;

  solArray = FindRoot[eq, {sizeOfArray, 0.01}];

  sizeOfArray = sizeOfArray /. solArray]
```

Coded in Mathematica

Equations are readable AND executable

Backsolve for the sizeOfArray variable

Body Design Rules

```
eq =
   1                                        attackAngle  densityWater π  vDiamAtTail ^2  speed^2 Sin  attackAngle  Cos  attackAngle
 ─────────────────────────────                                          ───────────
 vehicleDiam + 2 planeDepth                                                  2

        del            2  vehicleDiam
 ─────────────────────  ───────────── + planeDepth  == lift;
  planeDepth + del

sol = FindRoot  eq, planeDepth, 0.01  ;

planeDepth = planeDepth  sol;

       planeDepth
uc =  ────────────  ;
          del

      2  planeDepth del
us = ───────────────── ;
       vehicleDiam
       ───────────
            2

      2 vehicleDiam del                         vehicleDiam  3    2  1           ArcSin  us      us    1 - us^2
sw = ─────────────────────────────────── + ─────────────────────────────────────────────────────────────────────── ;
     Tan  attackAngle                             2         2                2 del Tan  attackAngle

                  1
friction = Abs   ─  densityWater speed^2 Cos  attackAngle  sw cd
                  2
```

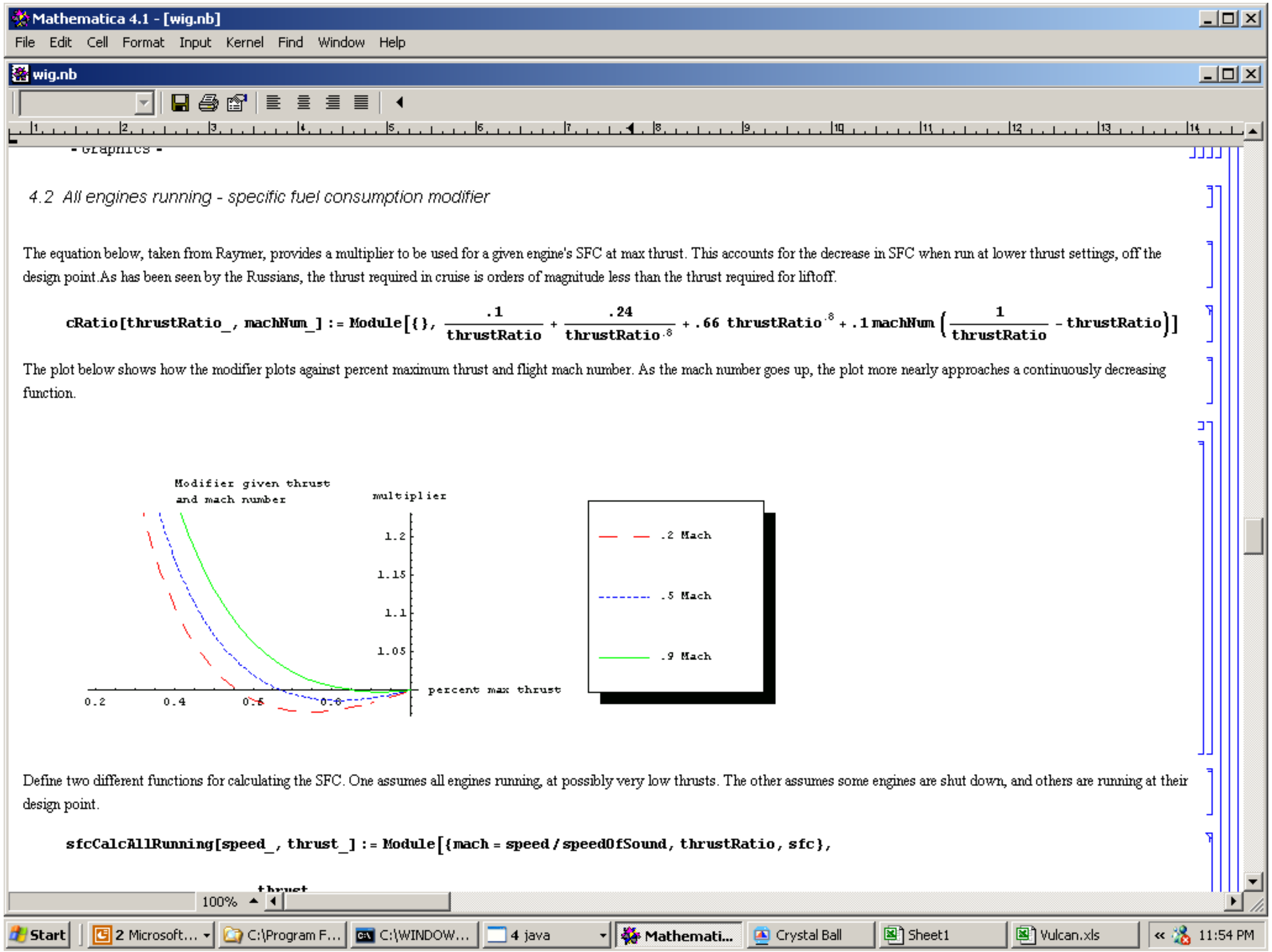
Solve for plane depth

Calculate coefficients

Calculate drag

Converted to Mathematica Document

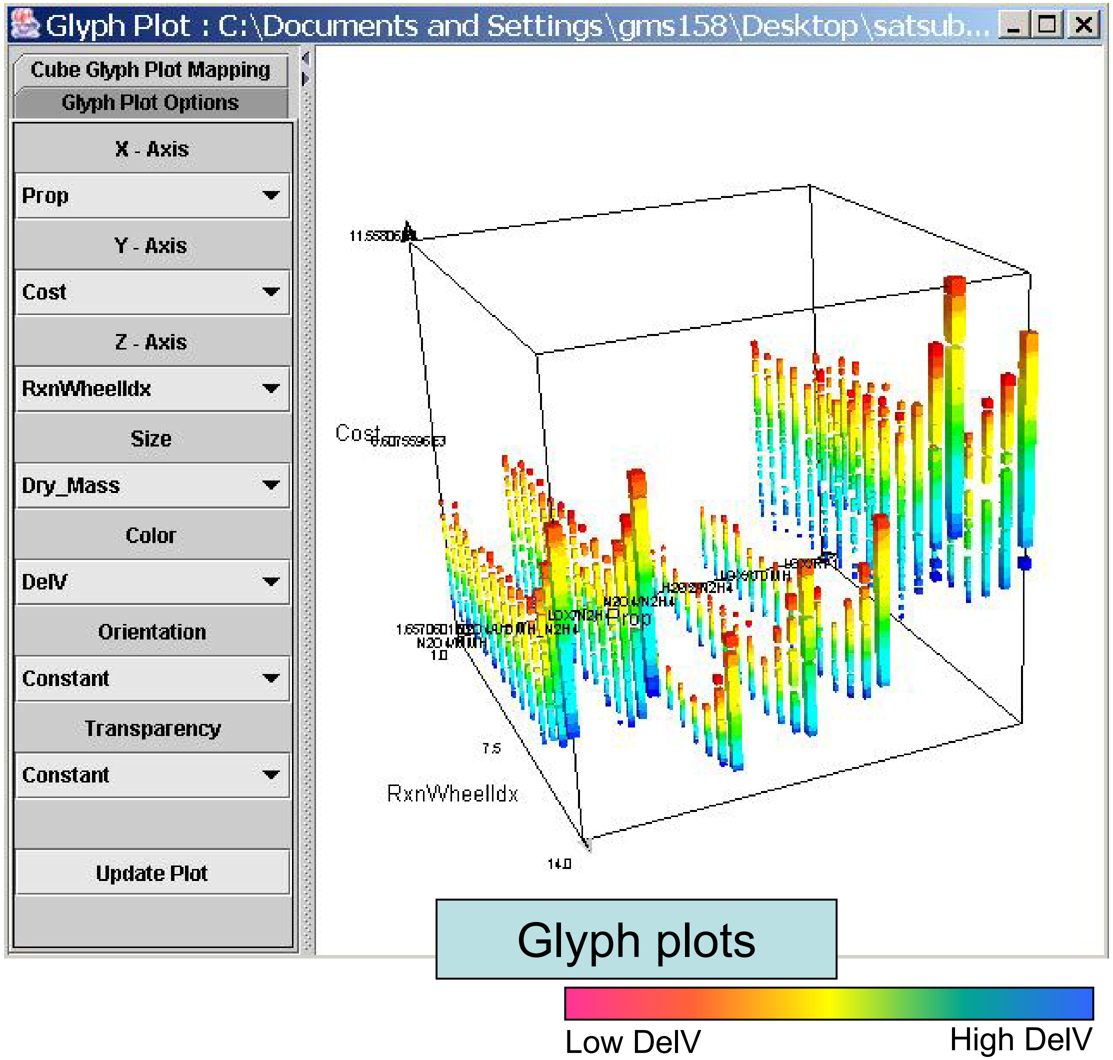
- Documents the rule set
- Also serves as executable model



PENNSTATE
Applied Research Laboratory

ARL Trade Space Visualizer (ATSV)

- Multi-dimensional Data Visualization Capabilities
  - Glyph Plots
  - Histogram Plots
  - Parallel Coordinates
  - Scatter matrices
  - Brushing/Linked Views
- Display multiple plots simultaneously



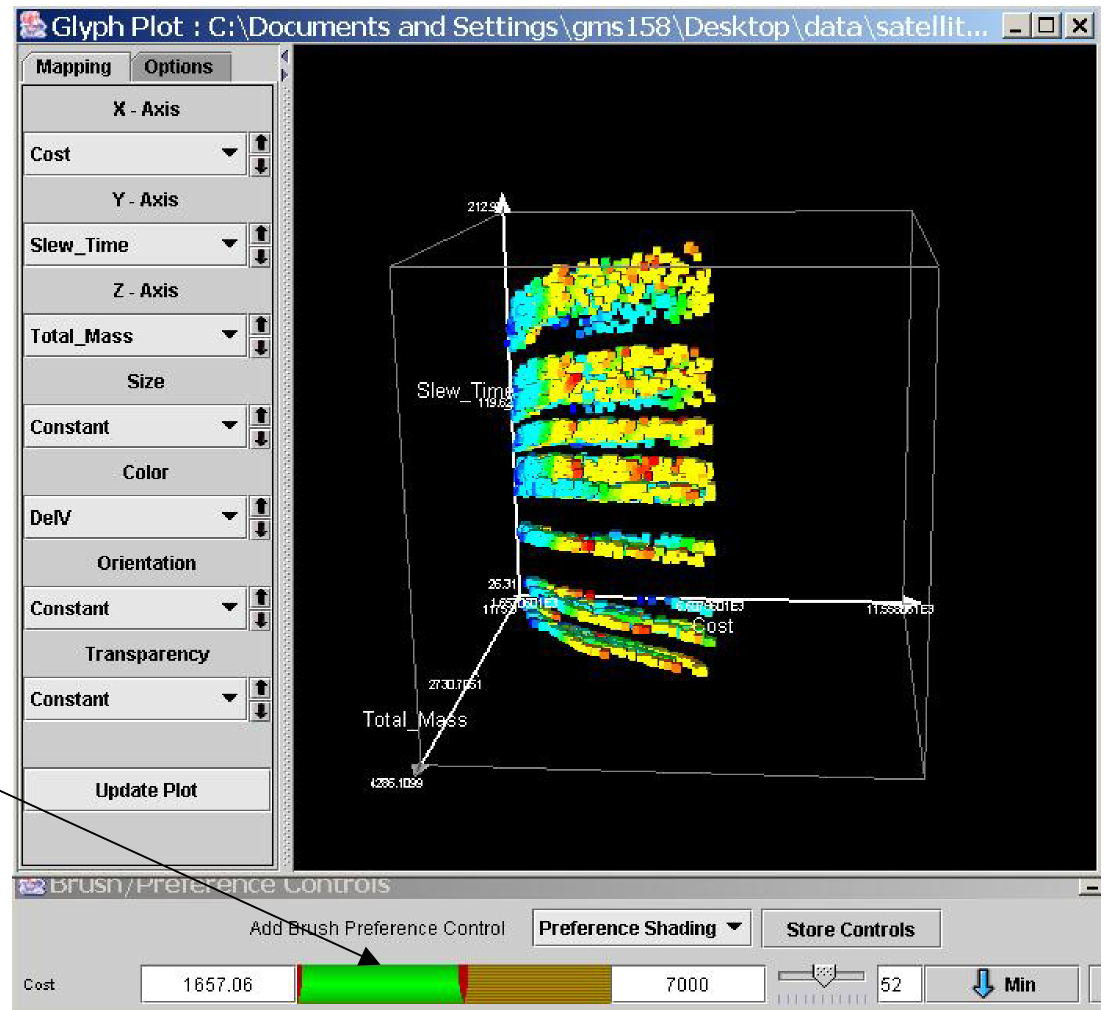
Glyph plots

Brushing

- Apply Constraints to the Trade Space

Brushing – A multi-dimensional visualization technique that only displays designs that satisfy a user-defined upper and lower bounds to the trade space

Show only designs that cost less than 7000 units

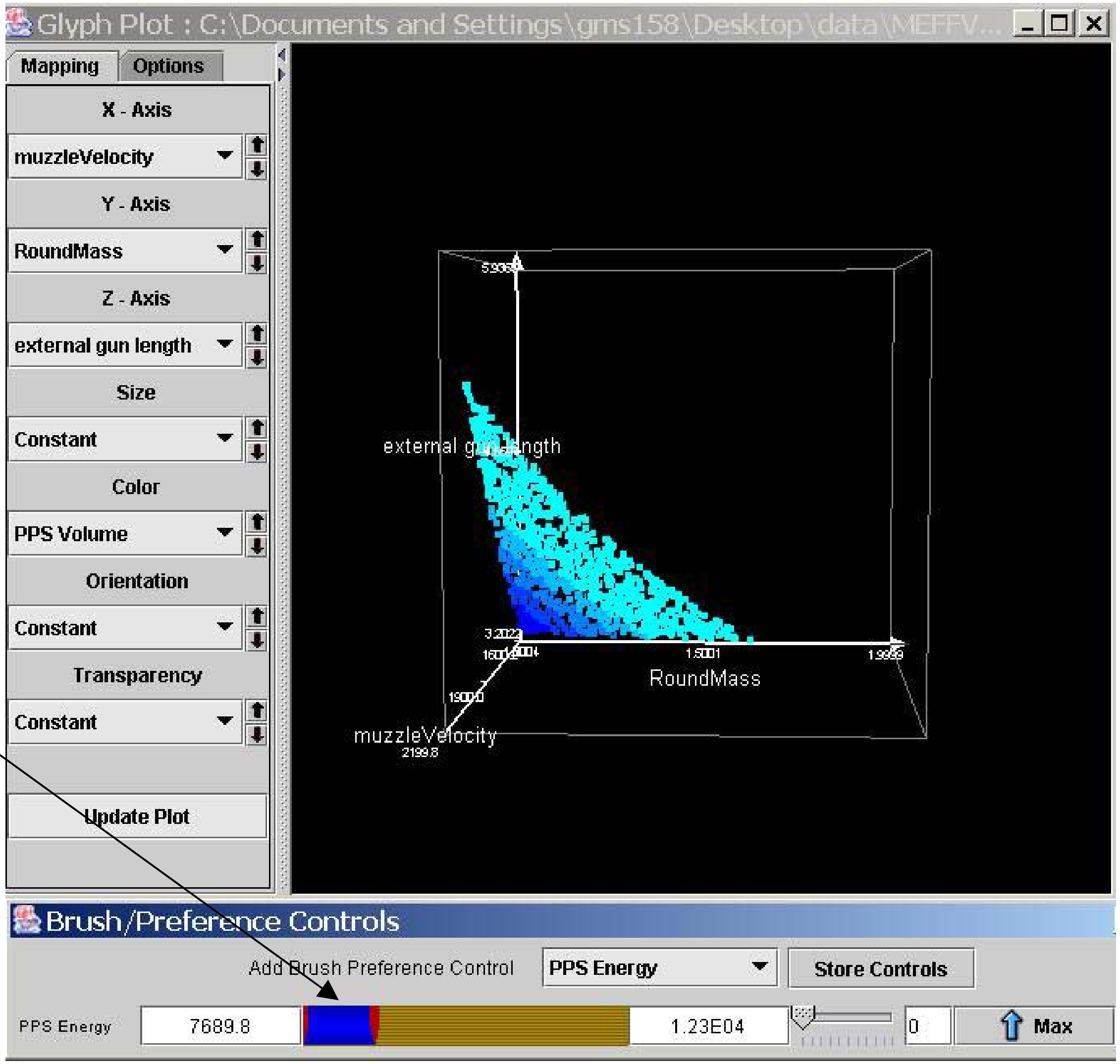


Brushing

- Visualize Trends

Brush a variable that is not displayed in the glyph plot

Apply a brush on PPS Energy



PENNSTATE

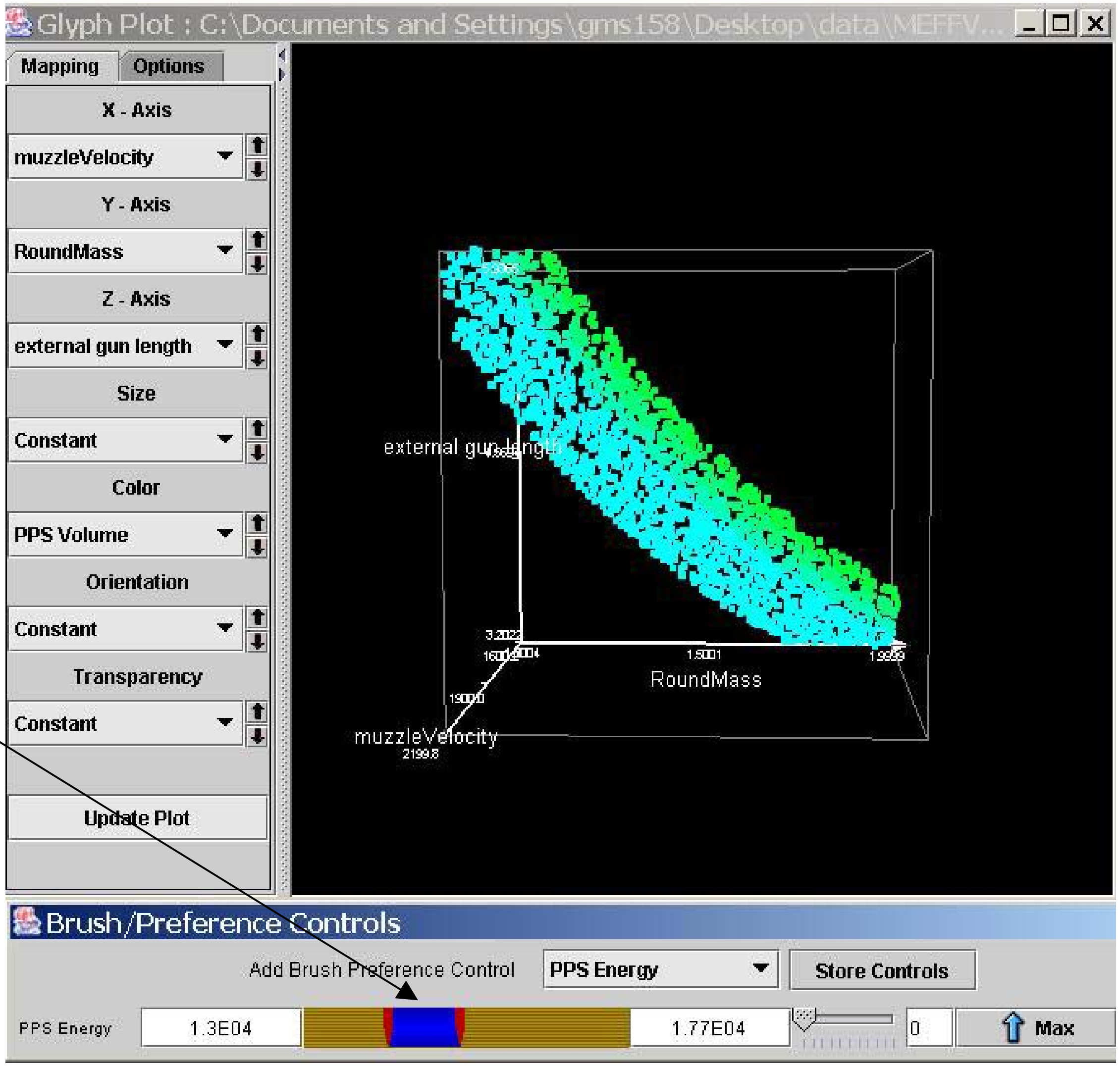
Applied Research Laboratory

Brushing

- Visualize Trends

Brush a variable that is not displayed in the glyph plot

Apply a brush on PPS Energy

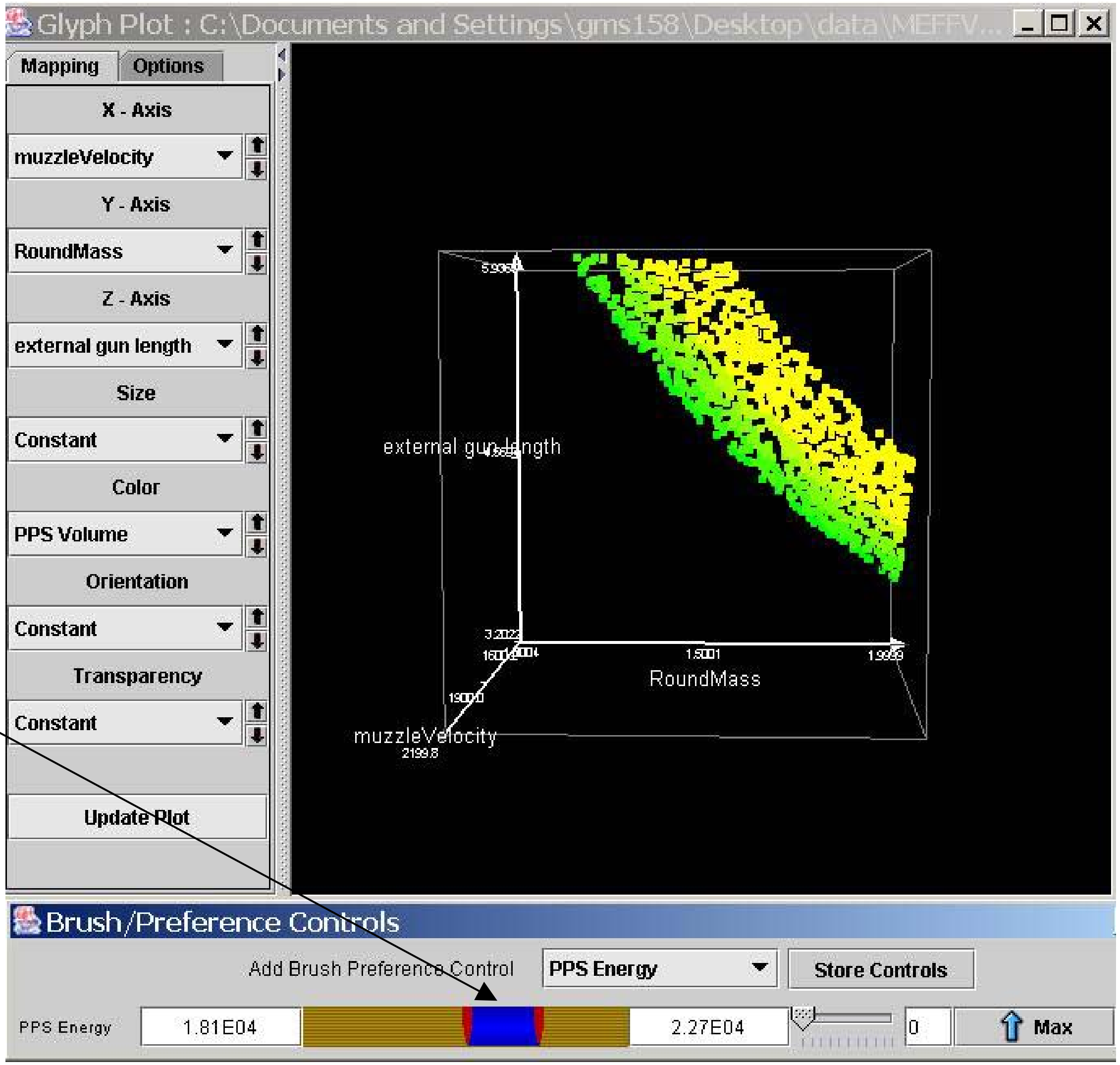


Brushing

- Visualize Trends

Brush a variable that is not displayed in the glyph plot

Apply a brush on PPS Energy

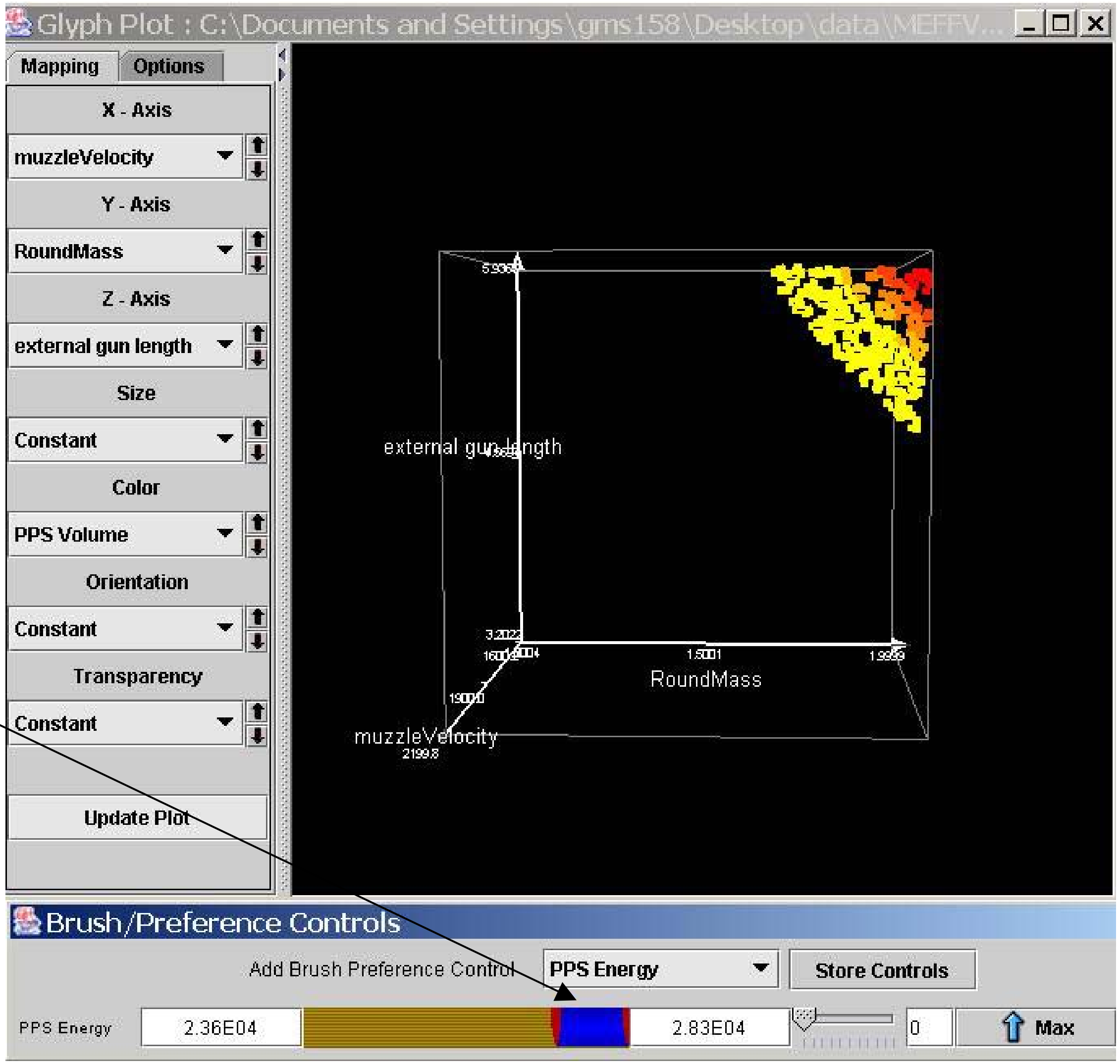


Brushing

- Visualize Trends

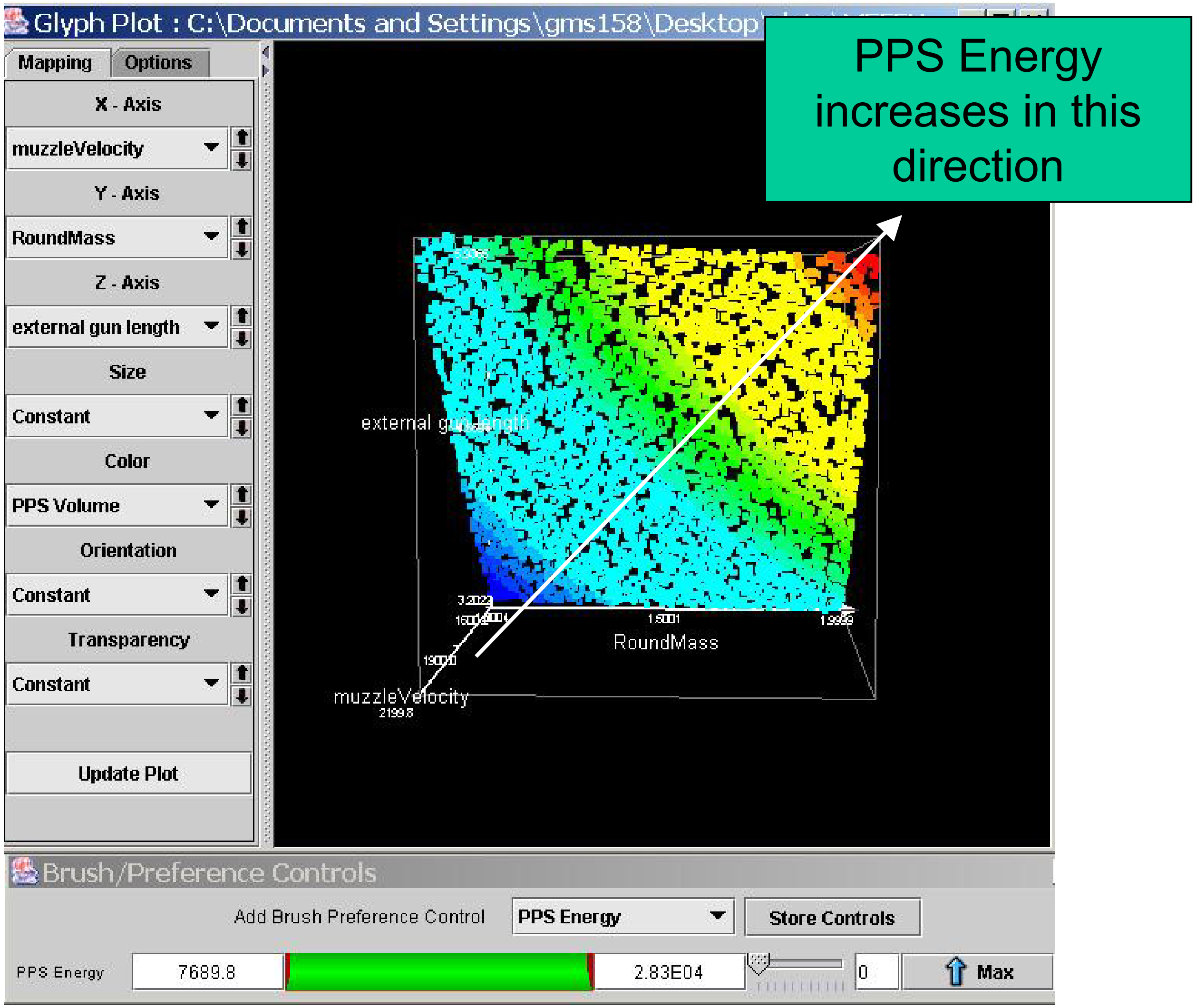
Brush a variable that is not displayed in the glyph plot

Apply a brush on PPS Energy



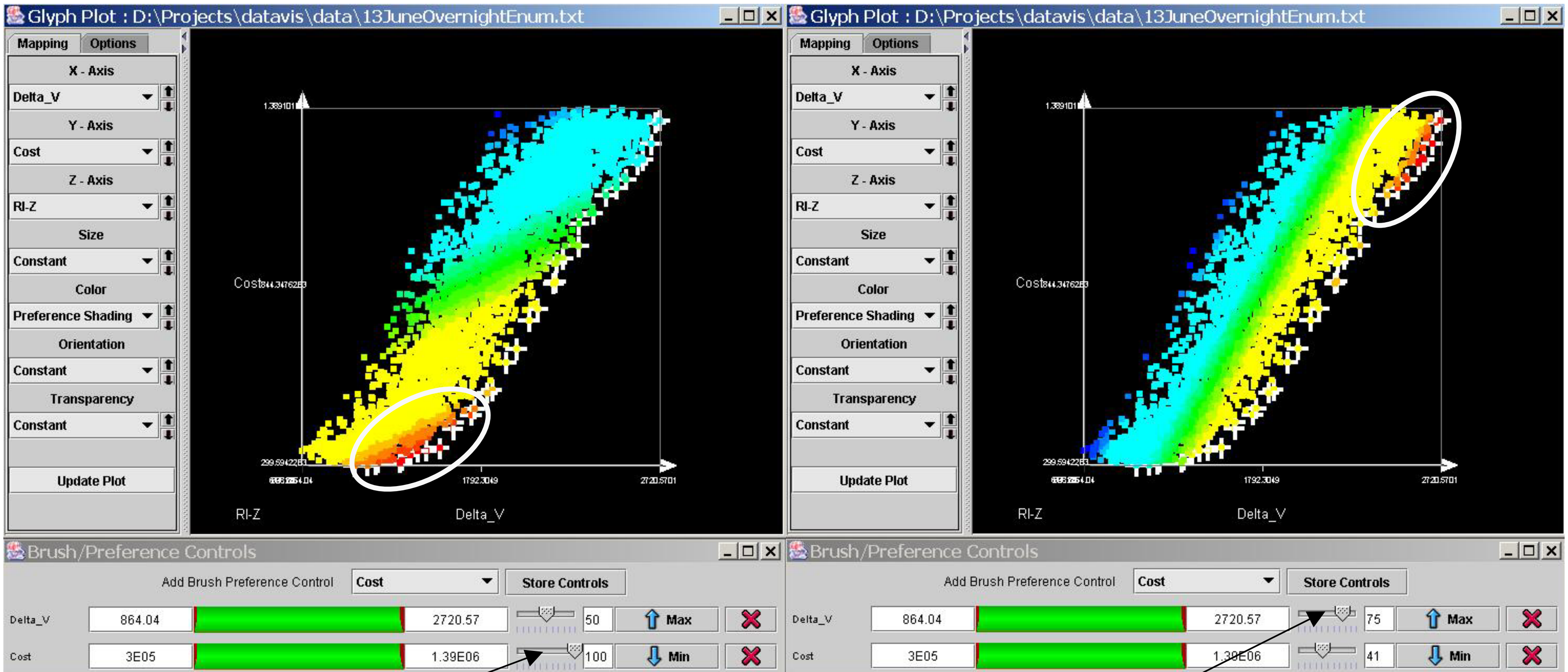
Brushing

- Visualize Trends



Preference Structures and Pareto Frontiers

- The ATSV can visualize preference structures and Pareto frontiers.
- Designs that lie on the Pareto frontier are identified with white markings
- Maximize Δ V and minimize cost

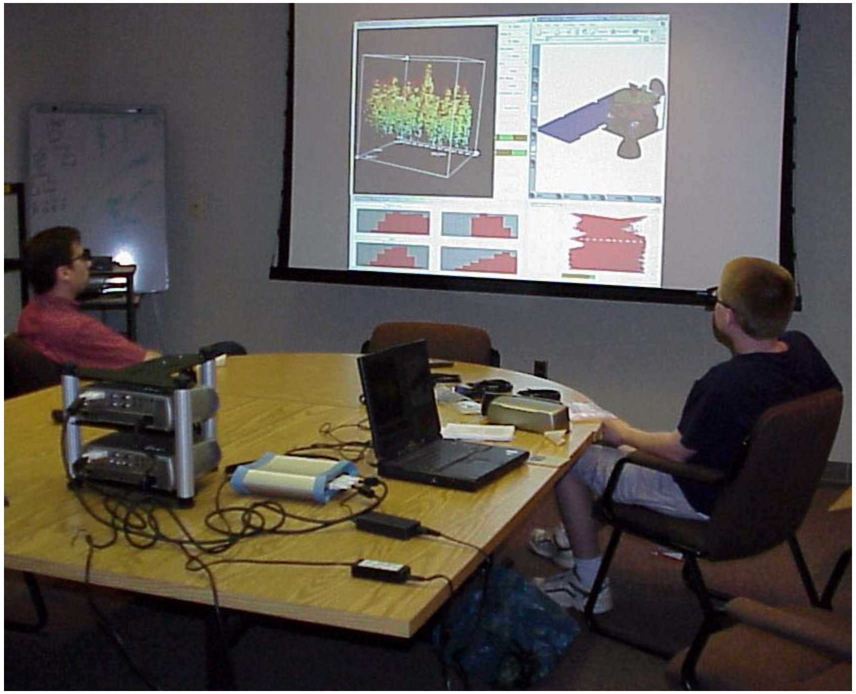


Greater importance on minimizing cost

Greater importance on maximizing ΔV

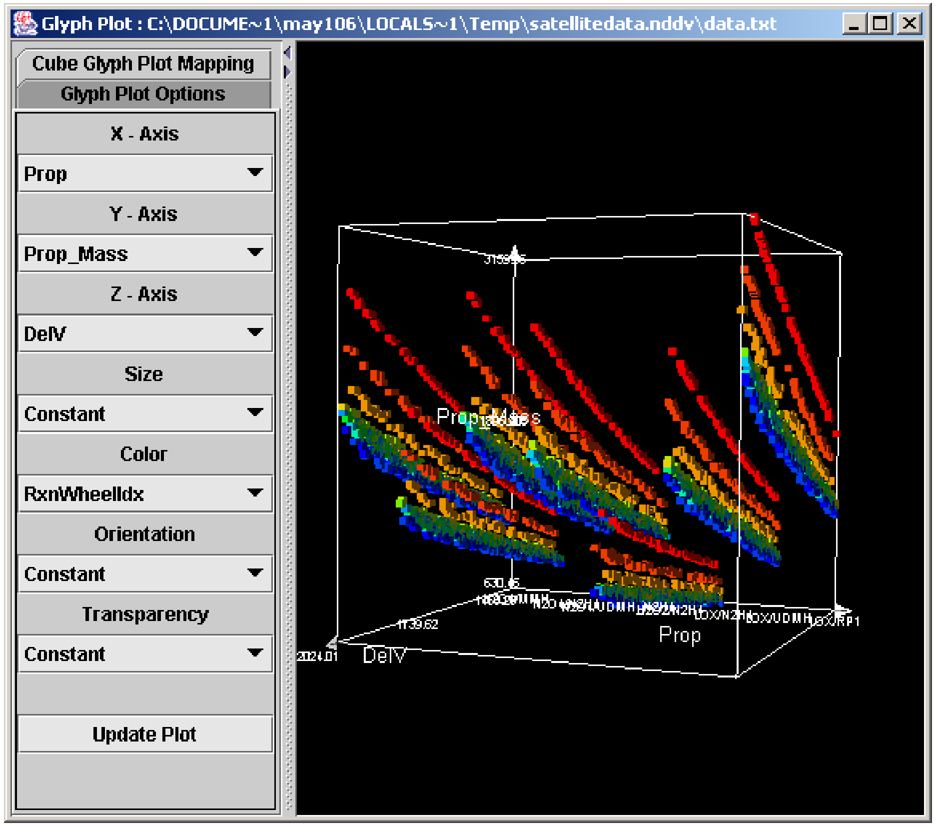
Stereoscopic Visualization

- The ATSV uses advanced visualization hardware that displays data visualization plots in stereo mode
- The Visualization Toolkit (VTK) is used to output data visualization plots in stereo mode



Demo-Enumerations

- Coords
  - Prop choice, prop mass, DV
  - Color – RW index
- Note individual curves for combinations

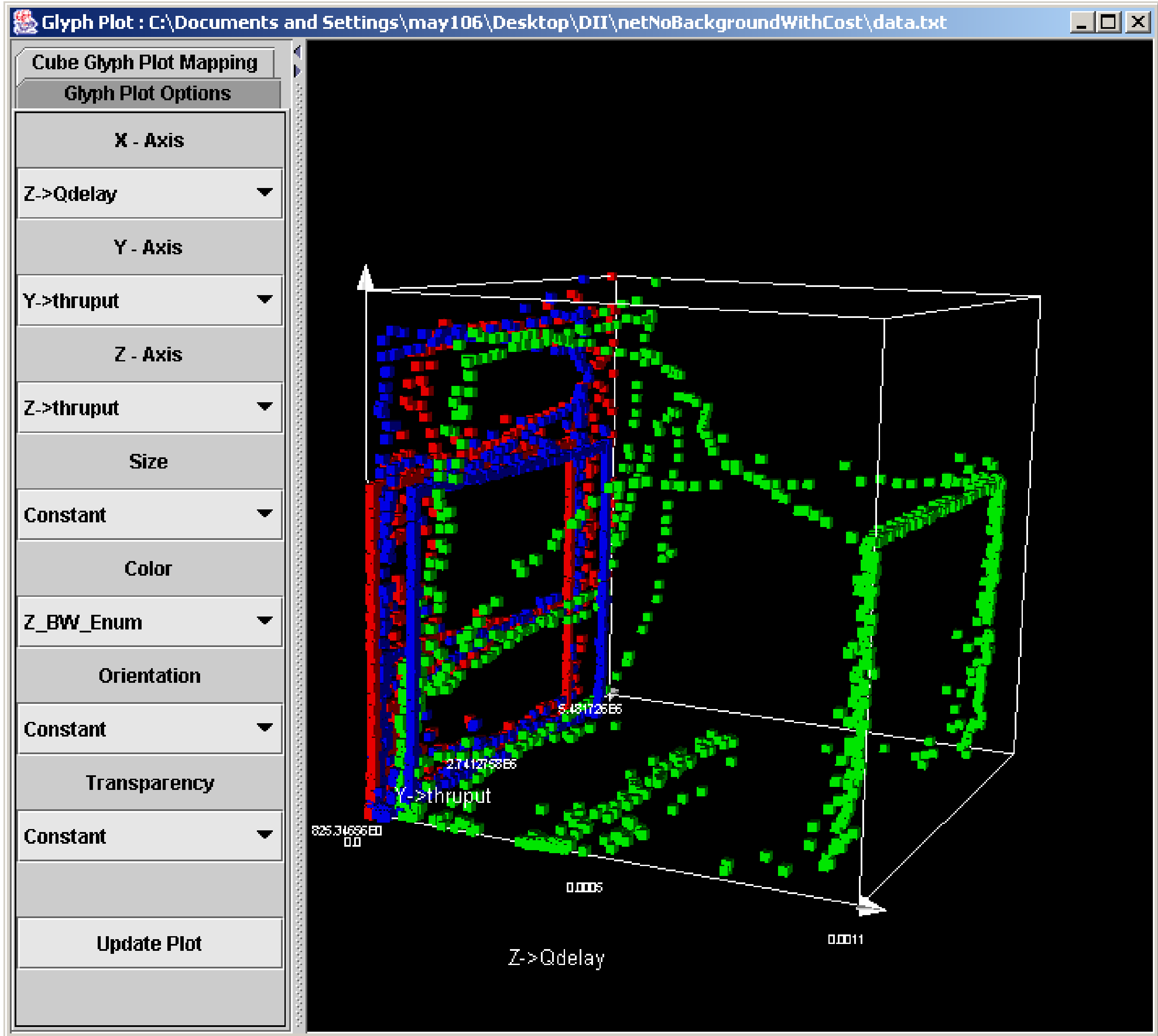


PENNSTATE

Applied Research Laboratory

Demo

- Coords
  - Z_Qdelay, Y_thruput, Z_thruput
- Note: Are patterns due to network performance or artifacts of Opnet?
- Brush variables to look for correlations

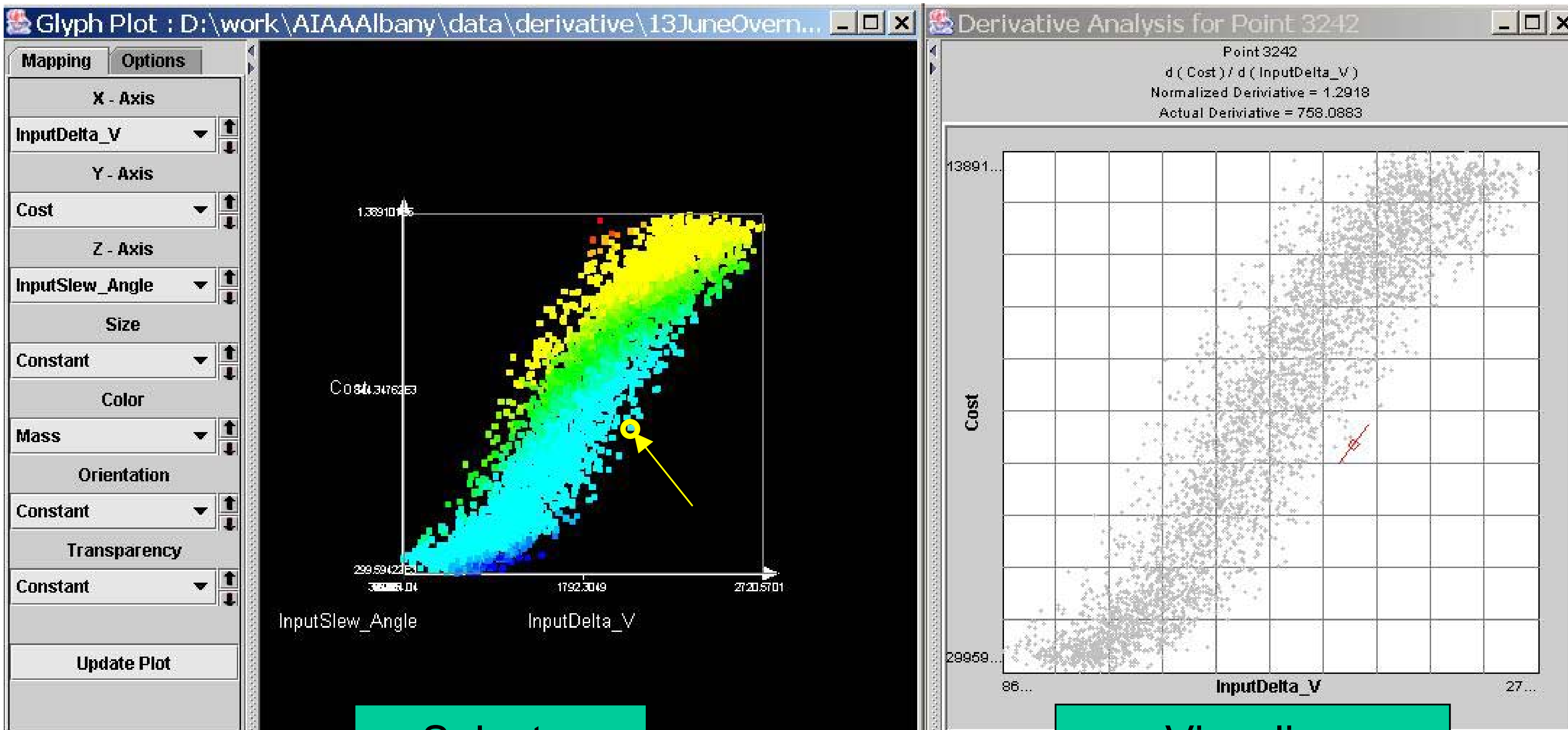


Recent Efforts

- Recent efforts have focused on extending the ATSV capabilities
  - Derivative display
  - Feature finder tool
  - Uncertainty visualization

ATSV - Derivative Display

- Motivation : Visualize derivative information around the selected point



Select a point in the glyph plot

Visualize derivatives at the selected point

Calculate Derivatives at a Design Point

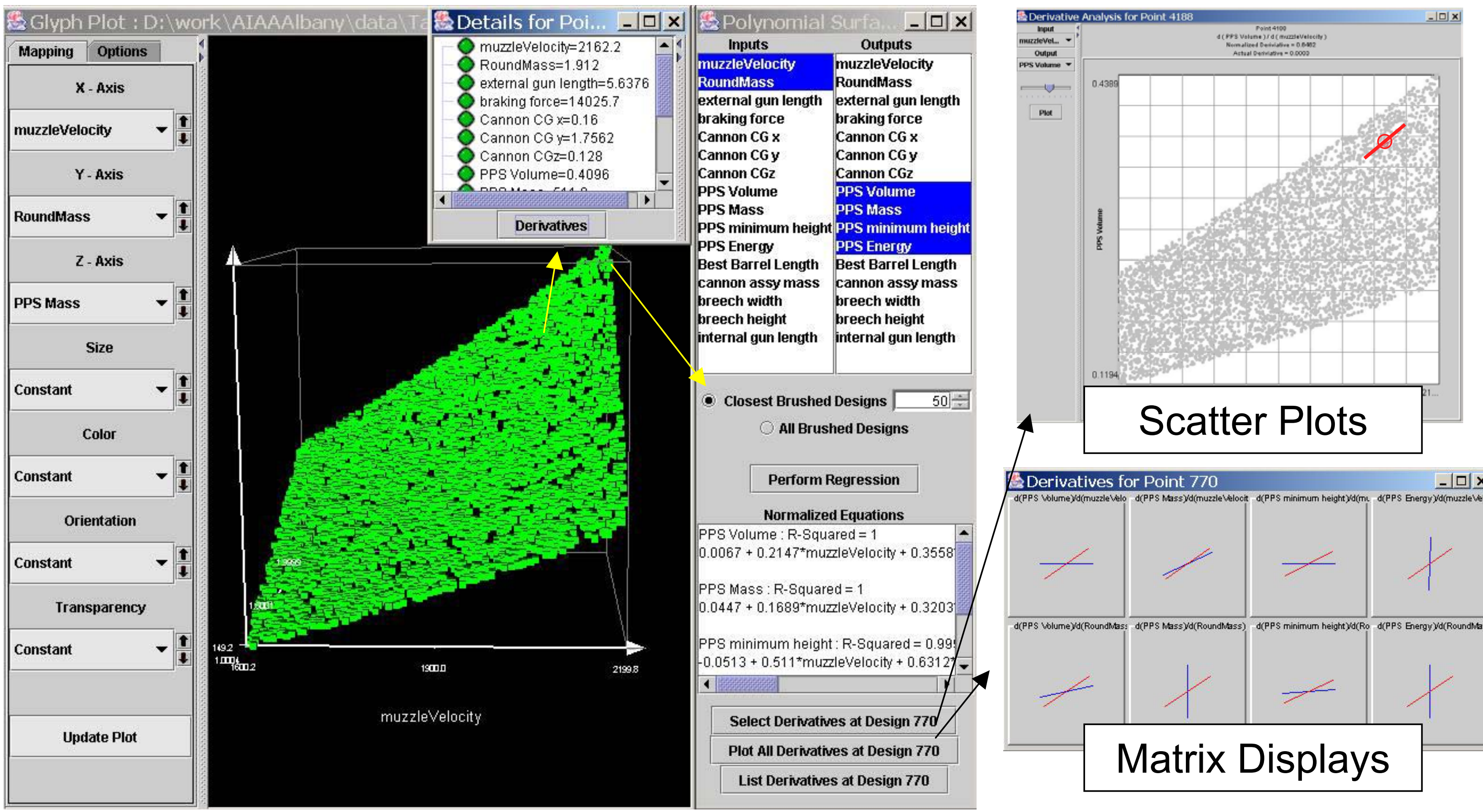
- Procedure
  - A user selects a point in the trade space and the ATSV fits a surface approximation at the point
- Least-Squares Fit
  - $y = Xa$, then $a = (X^T X)^{-1} X^T y$
- Derivatives at a selected point are calculated by using the first derivatives of the polynomial surface approximations.

ATSV Derivative Display

1. Select a point in the trade space

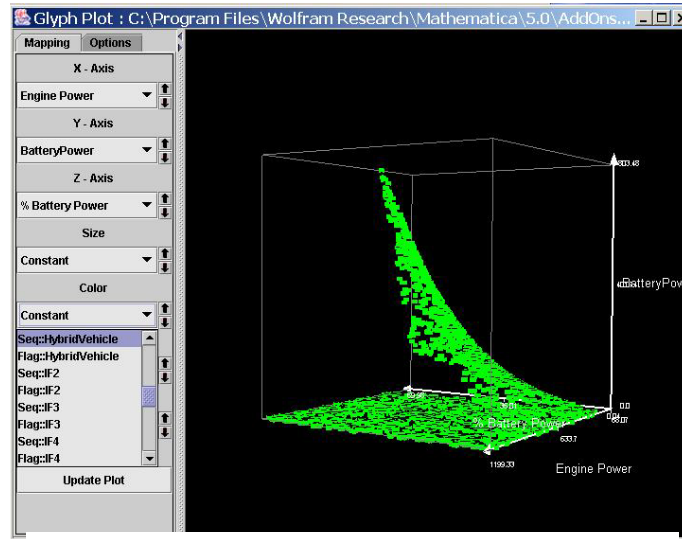
2. Calculate a polynomial surface approximation for each output selected

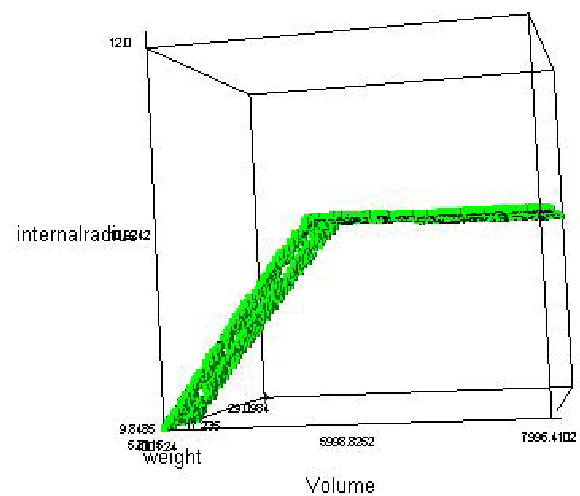
3. Calculate and visualize the slope at the selected point



ATSV - Feature Finder

- Trace interesting features in trade spaces to conceptual model design rules
- Examples of interesting features include,
  - Discrete trends
  - Isosurfaces
  - Knees in the curve
  - Second-Order trends
- Possible causes
  - Constraints
  - Logical branches in the conceptual model





Steps to Implement Feature Finding

- Instrument the code to record and report (via flags) paths taken in logical branches
- Modify ATSV to visualize the flags, let user look for correlation
- Modify ATSV to trace flags back to the originating line of code

If(a > b, conditionA, conditionB)

Store the value of a > b, True or False

Max(a,b,c)

Store the index of maximum value {a,b,c}, int

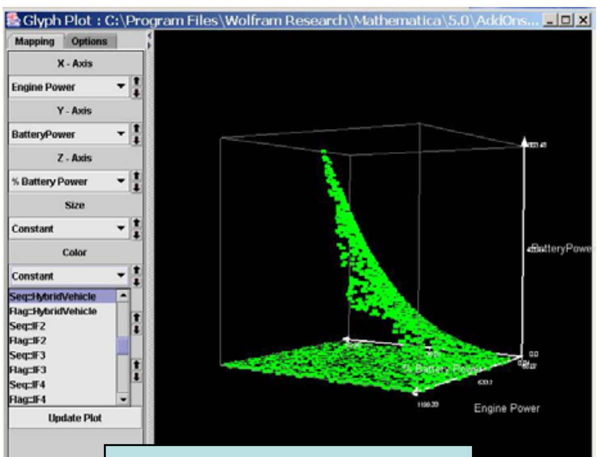
Min(a,b,c)

Store the index of minimum value {a,b,c}, int

Feature Finder Process

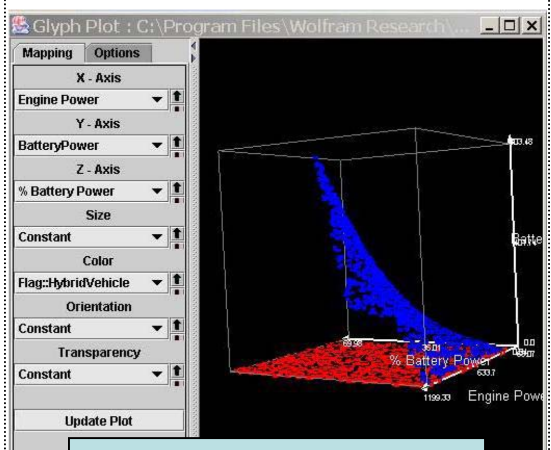
- Identify interesting features in trade spaces (ATSV plotting capabilities)
- Visualize design rules values and identify design rules of interest
- Trace back to the design rules in the conceptual model

1. Find interesting features



2 distinct isosurfaces

2. Identify design rules of interest



Find functions that switch on the interesting feature

3. Locate conceptual model design rules

Locate design rules in the conceptual model

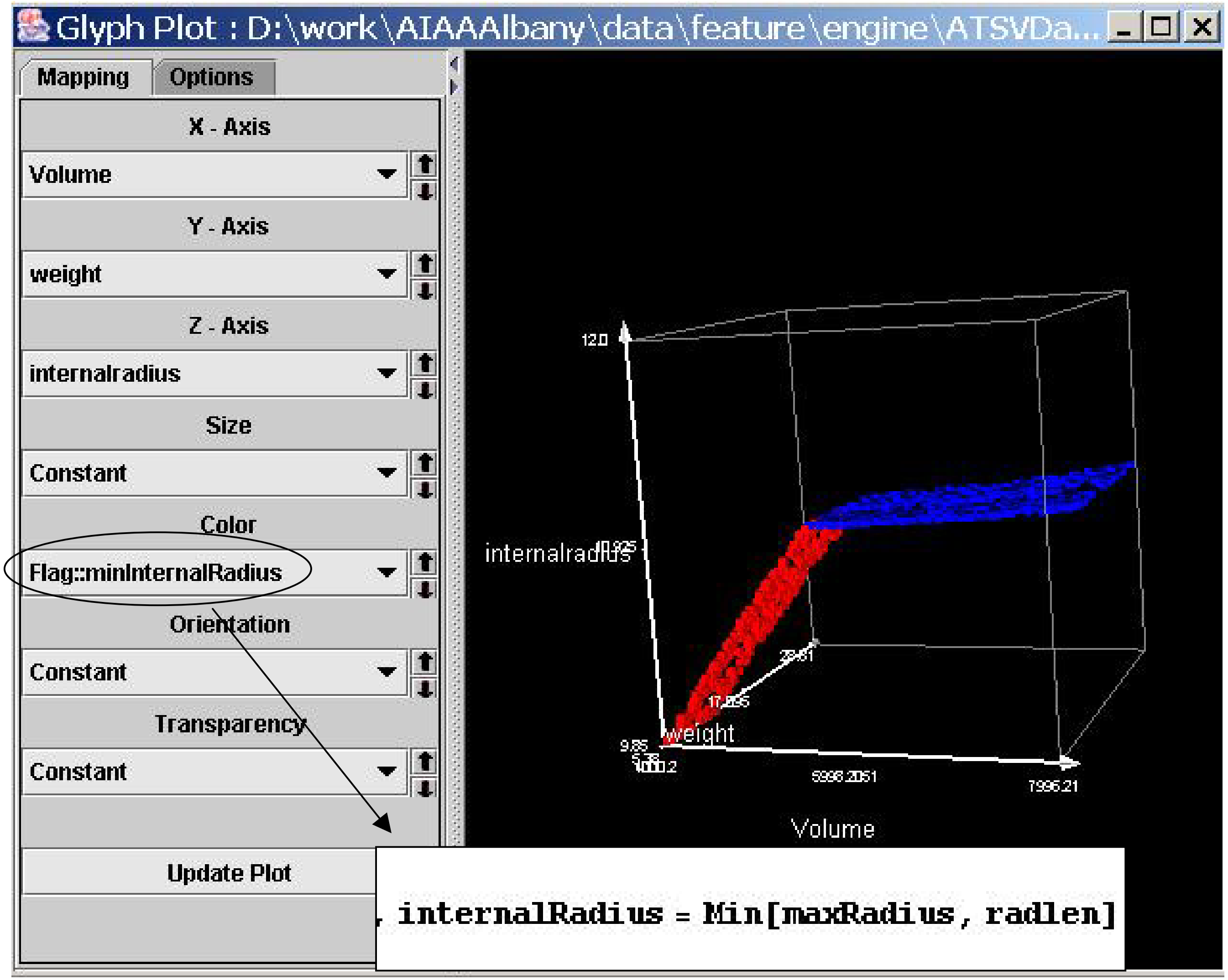
Design Example

This glyph plot displays a knee in the curve which is caused by tank radii reaching a sizing constraint.

To accommodate additional volume, spherical tanks increase their radii, until a limit is reached. Then, the tanks become cylindrical if more volume is needed.

Red designs : Spherical tanks

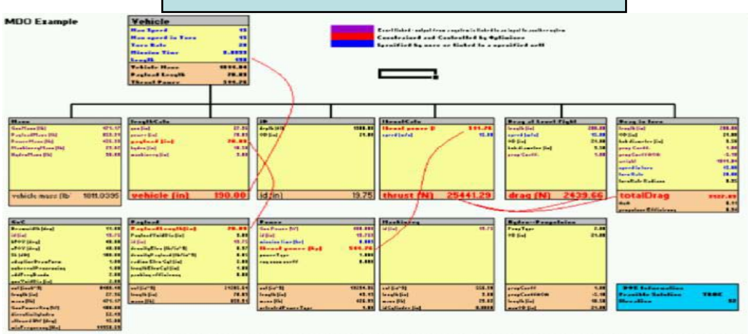
Blue design : Cylindrical tanks



ATSV - Uncertainty Visualization

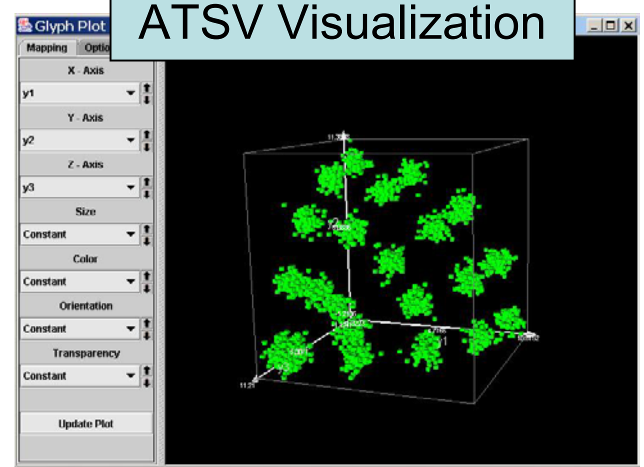
- Motivation : We are currently developing methods to capture a design’s uncertainty using conceptual design.
- As a result, the ATSV has been extended to visualize a design’s uncertainty

Conceptual Models



Developing methods to capture design uncertainty

ATSV Visualization



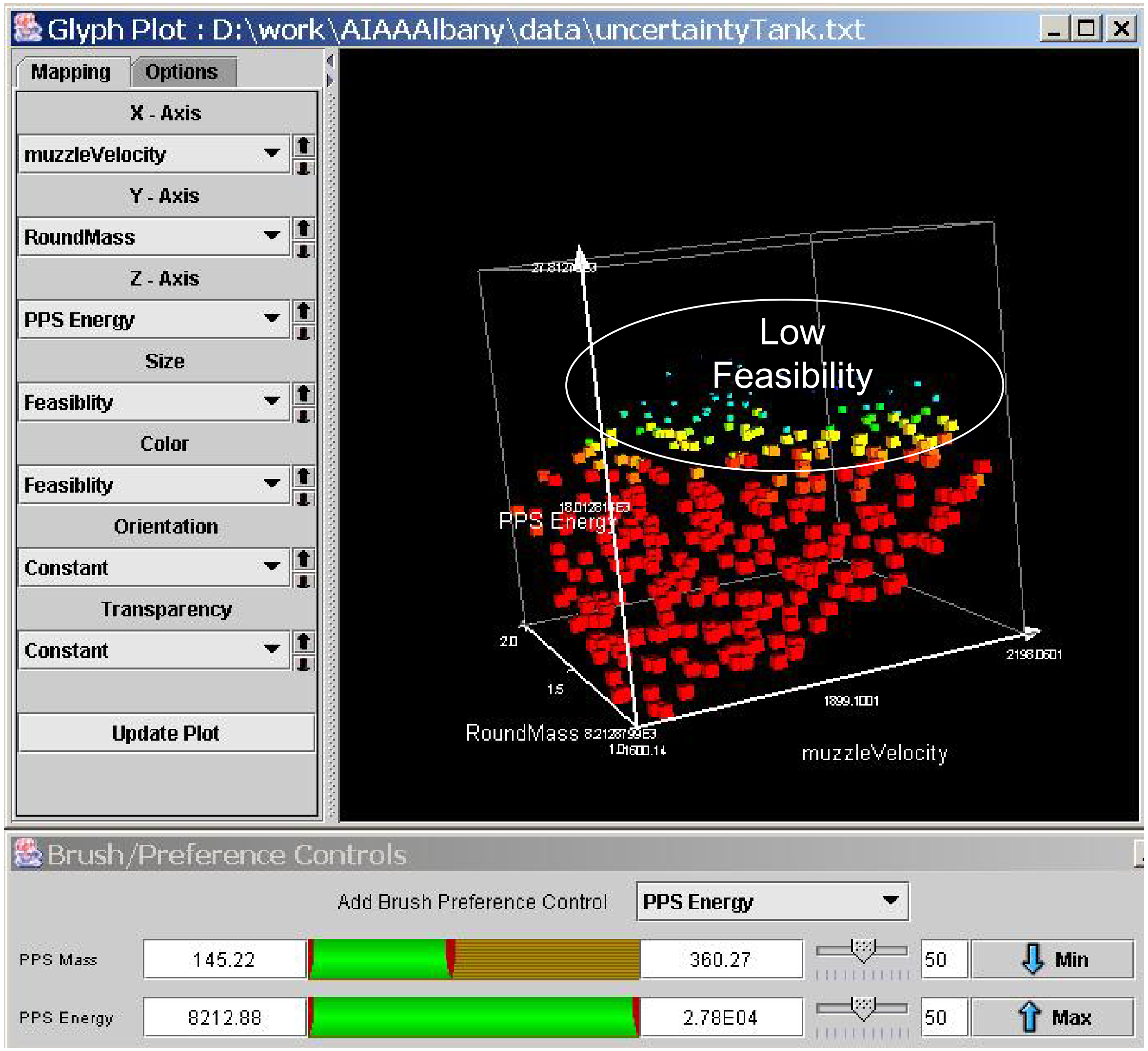
Visualize trade space along with each design’s uncertainty

Visualize Design Feasibility Using ATSV Plots

- The ATSV stores a design's feasibility and treats this metric as an extra dimension in the trade space.
- For example, the feasibility of a design is mapped to the color and size of the glyph cubes.

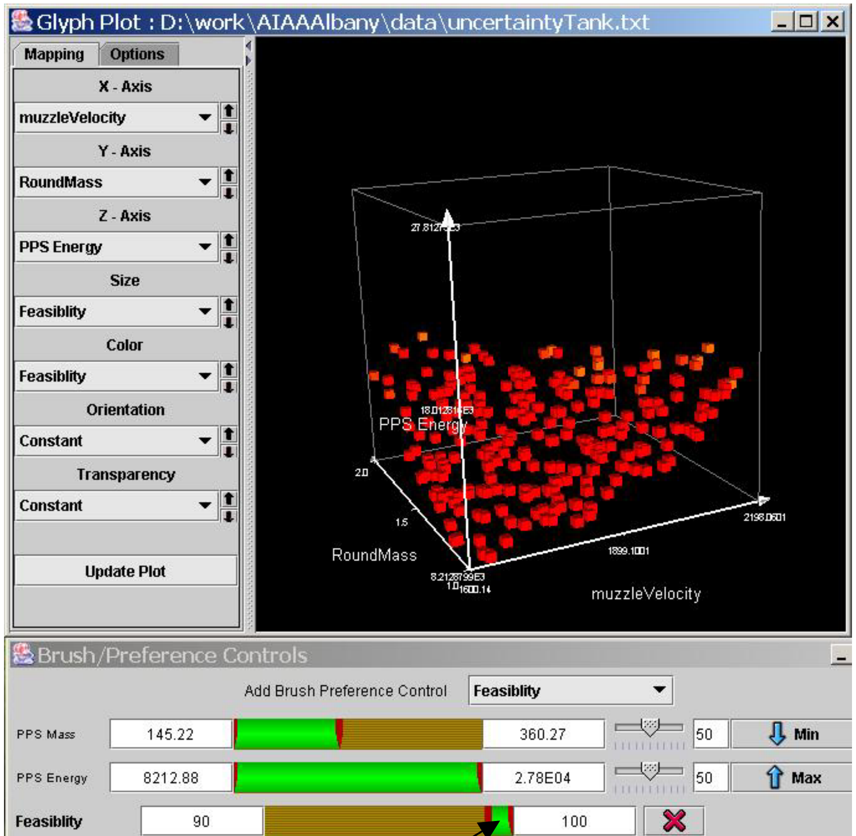
Large red designs : High feasibility

Small blue design : Low feasibility

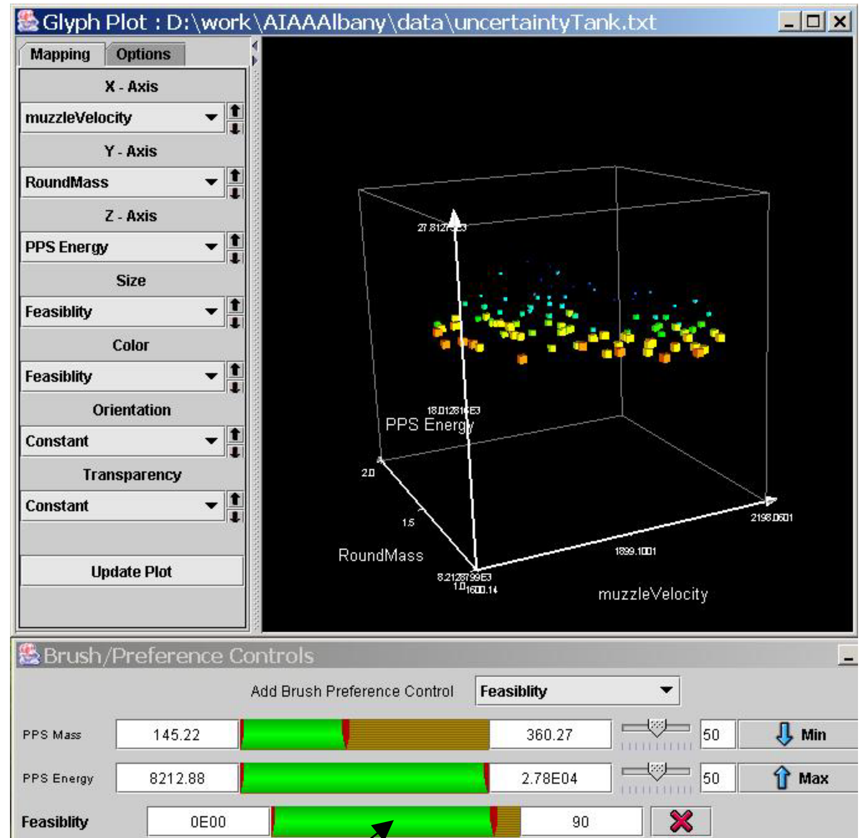


Brush Feasibility

- User can apply constraints to design feasibility



Show only designs that are
90% - 100% feasible



Show only designs that are
0% - 90% feasible

Summary

- Extended ATSV capabilities to include derivative display, the feature finder tool, and uncertainty visualization
- Questions or comments …